INVESTIGATING THE POTENTIAL IMPACTS OF THE ARABIAN MINE ON WIDENING OF SR 68, MOHAVE COUNTY, ARIZONA

Robert Cummings, P.E., Saguaro GeoServices, Inc. [1]
Nick Priznar, Arizona Department of Transportation[2]

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ABSTRACT

A proposed expansion of Arizona State Route 68 was realigned to avoid undermined areas of the Arabian Mine group. The Arabian is an inactive underground mine in northwestern Arizona that recovered precious metals from before 1917 into the 1930s, using the shrinkage stoping method. The property, which consists of patented and unpatented claims, includes workings exposed at the surface (inclined shafts, drifts, open cuts, and stopes) within a few hundred feet of SR 68, then a two lane highway serving Bullhead City Arizona, Laughlin, Nevada, and points beyond, including Las Vegas. A dramatic recent increase in traffic led the Arizona Department of Transportation (ADOT) to initiate a corridor study to upgrade SR 68. A mine literature search disclosed that the mine was developed along a vein system that roughly parallels the highway, and that the workings extended downward a considerable depth in the direction of the highway. Moreover, large, open voids were indicated. In 1991, a mine survey and underground reconnaissance confirmed the presence of large open stopes. Deep reconnaissance was not possible because the workings were found to be flooded with water just below the 100 level. However, observations of the extent and condition of the accessible workings raised questions about the long-term stability of the deeper workings, thought to underlie or adjoin future roadway improvements. Cross hole geotomography, conducted under a cooperative agreement between ADOT and the U.S. Bureau of Mines, disclosed the presence of underground voids approximately in the expected locations, but could not resolve the exact dimensions of the voids, nor the condition of the surrounding rock. Inasmuch as future stability of the workings could not be assured, especially given a history of domestic water extraction from the workings and statements of future mining intentions by the property owners, a decision was ultimately reached to relocate the expanded, four-lane SR 68 in an area known to be free of undermining.

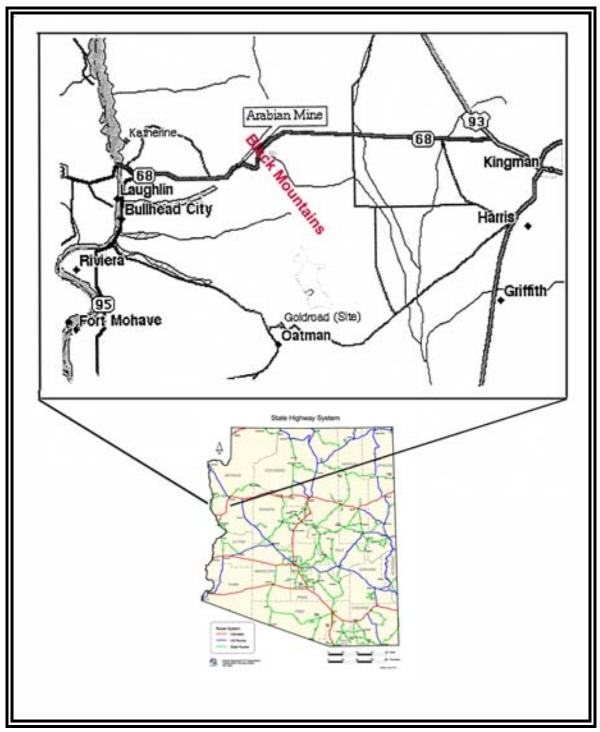

Figure 1 – Project location

BACKGROUND

In northwestern Arizona, Arizona State Route 68 runs from a point north of Kingman westward into Bullhead City. The project area (Figure 1) is along SR 68 about 9 miles east of Bullhead City, at the Arabian Mine. It is in the southwestern foothills of the Black Mountains, which are part of the Basin and Range Physiographic Province on the eastern flank of the Lower Colorado River Corridor.

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[1] President, Saguaro GeoServices, Inc., P.O. Box 44154, Tucson, AZ 85733

[2] Engineering Geologist, Materials Group, 1221 North 21st Avenue, Phoenix, AZ 85009

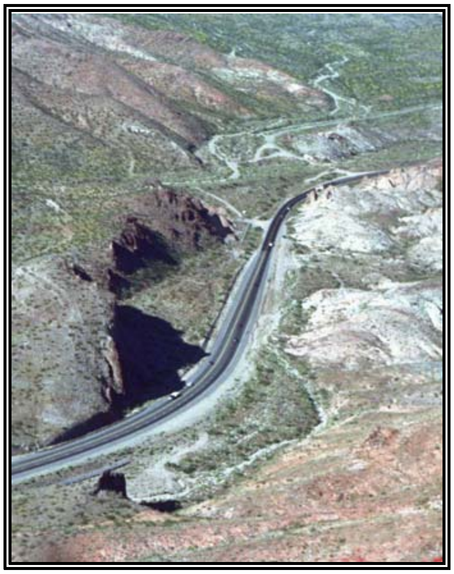

Figure 2 – Physiography near the Arabian Mine

The project area is situated in the arid Mohave Desert Region where the annual precipitation averages a little more than 5 inches per year. During the summer months, temperatures can easily exceed 100 degrees. Because of the climate of the region, soil cover is poorly developed and chiefly confined to slope debris and Quaternary alluvial soil deposits (Figure 2). Desert vegetation is quite sparse, and most of the individual plants are small. Desert vegetative species primarily consists of creosote, catclaw, and thorny ocotillo, with occasional paloverde and ironwood trees.

Geologic Setting

The Black Mountains are dominantly composed of three sequences of middle to early Tertiary aged volcanic rock. In order of deposition they are known as the: Patsy Mine, Golden Door, and Mount Davis volcanic sequences. These volcanic deposits occur with varying unconformable and or faulted contact with an older Precambrian metamorphic and igneous complex locally known as the Katherine Granite.

Regional faulting consists of two dominant sets of northwest to southeast trending faults which appear to roughly parallel the orientation of the Black Mountain Range. According to Longwell 1963, "Most of the faults are normal. But at least two of the largest have reverse displacement along much of their exposed lengths. Blocks between the faults are generally tilted, and in the tilting movement several large faults were rotated to low angles of dip". In contrast to these regional trends, the project area exhibits an exceptionally persistent northeast to southwest trending, east dipping set of discontinuities we have referred to as the Arabian Fault Zone. These structures separate the Precambrian Katherine Granite Complex from the Tertiary Volcanic sequence.

The region has been widely explored for precious mineral deposits over the past 150 years. According to Faulds and others (2000), Miocene dikes and veins of rhyolite, andesite, quartz, and calcite, have intruded pre-existing easterly dipping faults and are associated with mineralization in the Katherine District. Outcrops in the vicinity of the Arabian Fault Zone appear to support this observation. A portion of a recent geologic map (Figure 3) shows the local geology.

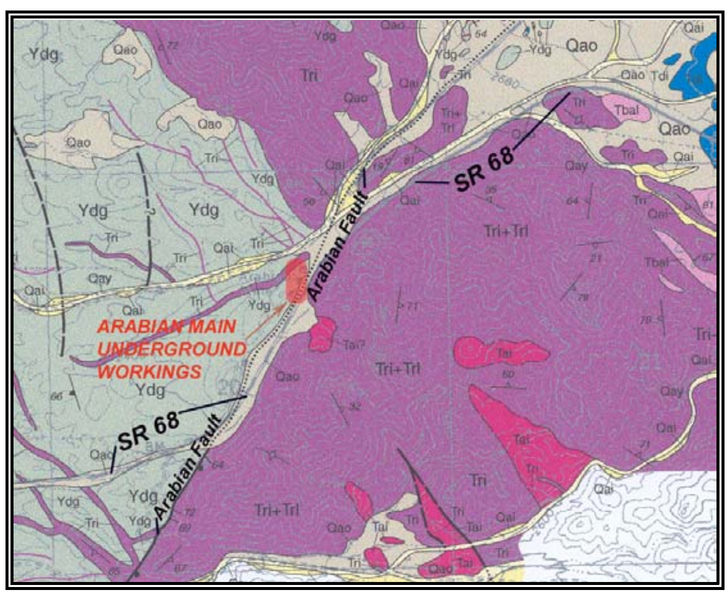

Figure 3 – Area geology (after Murphy, 2003)

Changes in the base level and meandering of the Colorado River have created additional Tertiary alluvial sediments in the form of river and lake deposits isolated from the existing incised drainage channel. Uplands consist of a dissected pediment, alluvial fan and bajada morphology with overlapping terrace deposits which are interrupted by relic monoliths of weirdly shaped volcanic materials that punctuate much of the region's slopes.

Development of the SR 68 Corridor

The exact origin of the route is lost to history; however, it lies very near overland trails utilized by the Captain Lorenzo Sitgraves survey expedition exploring a transcontinental railroad route in 1851.

Although it is now hard to envision, the Colorado River was for many years a navigable waterway. As early as 1871, ships from San Francisco sailed to Mexican ports in the Gulf of California. There goods and passengers transferred to shallow draft steam powered boats to travel to numerous points along the Colorado River. A site now known as Katherine Landing provided primitive embarkation facilities to the military and mining pioneers of latter part of the 19th century.

As local roads developed they tended to originate from sites near the river and migrate away to livestock watering facilities or centers of commercial interest. Therefore, until late in the19th century, unimproved dirt roads connected the river to mining properties along routes most easily accommodated by terrain. The complete isolation of the district resulted in mining companies to shipping their ores to Europe for processing during those years.

Construction of the Atchison Topeka and Santa Fe Railroad redirected commercial interests towards the railhead at Union Station (eastern foot hills of the Black Mountains). A primitive road was established (by 1909) to connect the mining supply center in Chloride, Arizona over Union Pass to Nevada via a ferry across the Colorado River. This route is shown on a map that is part of USGS Bulletin 397, and is probably part of the Katherine Mine Road or the Road to Hardyville.

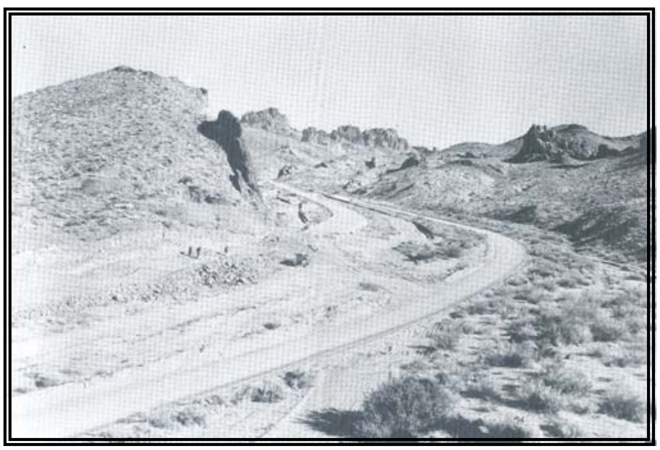

Figure 4 – USBR construction of what is now SR 68

Until the 1940s, there was no graded roadway along what then became SR 68 past the Arabian Mine. The US Bureau of Reclamation undertook significant modernization to the former routes during the construction of Davis Dam (circa 1942-1953)(Figure 4) . The regrading and paving facilitated transportation of power generating equipment, (by tractor trailer) from the established railheads over the Black Mountains to the dam site on the Colorado River.

ADOT Project No. S-10(1) constructed in 1946 established a 24' wide, 2.5" thick mixed bituminous surface on varying thickness of select base course for 26 miles over mountainous terrain. The highway plans recommended 1.5:1 fill slopes and a 4.5% to 5% grade. The plans indicate that the new highway would overlie existing abandoned mine workings along the route in the vicinity of Arabian Wash.

The westbound descent from the summit of Union Pass consists of almost 12 miles of 5% - 6% grade that terminate on the outskirts of Bullhead City. Within the last 30 years a tremendous increase in the region's population and transportation infrastructure has resulted from the gambling and tourist industry in Laughlin Nevada. Traffic demands, combined with the long, unbroken steep grade to Union Pass and the high summer temperatures, created long queues of traffic, and mandated modification of the two lane rural road. Some climbing lanes were developed in the early 1990s, but none in the Arabian mine area. In 1992 a portion of the highway just south of the main underground workings was realigned to improve a hazardous curve and correct a limited site distance problem. At the time, project designers became aware of past mining activities and the history of the road being constructed over abandoned workings.

In the late 1980s, ADOT began working on a corridor study to develop a comprehensive solution to the increasing demand. The final recommendation was a four lane divided highway with 38ft paved roadways and 46 ft to 16 ft medians. Opposite the mine, two new westbound lanes would be added. As the project developed, concern about potentially hazardous conditions led to the investigation of the Arabian Mine and Rising Fawn underground mine workings close to the roadway alignment.

Arabian Mine History and Development

The Arabian Mine property consists of three patented claims (southwest to northeast, the Perry, Rising Fawn, and Resaca), and a large group of adjoining unpatented claims including the East Philadelphia (Figure 5), which adjoins the Resaca on the northeast, in Section 20, T21N, R20W. The Rising Fawn was staked just after the turn of the century and the other patented claims soon after. By 1915 considerable underground

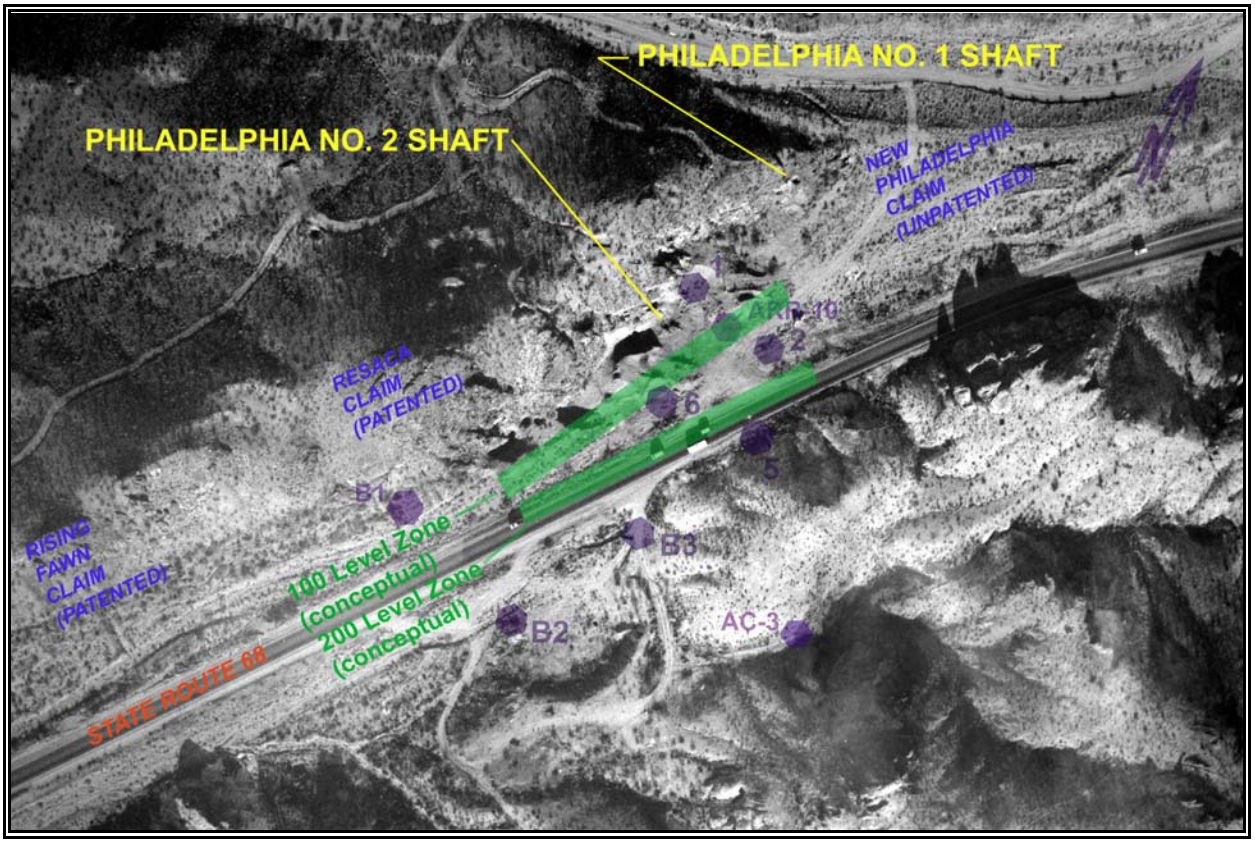

Figure 5 – Arabian Mine features. The SR 68 new lanes would be west of the existing.

workings had been developed and the major shafts on the property (including the still-existing Philadelphia Nos. 1 and 2, and the R-A, R-1 and R-2 shafts which no longer exist as such) had been sunk, along with several hundred ft of drifting. The main mine was worked intermittently into the 1930s.

The principal mined commodity was gold, occurring largely as free gold within a crushed quartz matrix. Production reportedly reached 50 tpd during some periods of operation; altogether, production was in the neighborhood of 50,000 tons.

Apparently, early production and mine access were through the R-1, R-A, and R-2 shafts. Careful cross-checking of field conditions against the records show that stoping conducted after 1930 (probably between 1934 and 1938) has obliterated these shafts.

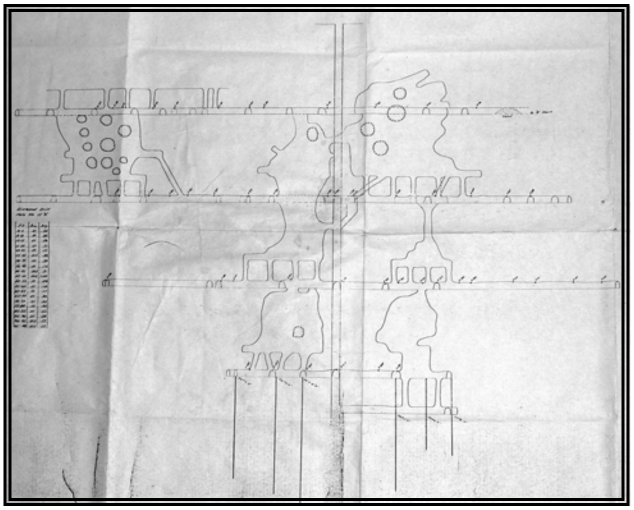

Figure 6 – Stope map by G.F. Chock, 1938

Following a dispute with the former mine owners, the Mines Company developed the Philadelphia No. 1 and Philadelphia No. 2 shafts on an adjoining claim to the northeast. The No. 2 became the main production shaft for the operation. It was 280 ft deep by 1915, according to old mine reports. Sometime after 1930, a survey by a G. F. Chock (undated but traced by a Fred W. Becker in November 1938) was used to generate a longitudinal section in "the plane of the vein", and is the only depiction of the stopes developed (Figure 6). This section shows the Philadelphia No. 2 to extend below 300 ft, with levels and stoping to what appears to be the 250 ft level. Other records indicate that the Philadelphia No. 2 Shaft reached 500 ft, but there are no records indicating stoping to this depth. The shaft was originally timbered through a muck pile and is inclined about 60 degrees just below the collar, flattening with depth to about 53 degrees. Most of the records agree that levels exist at 100 and 200 ft; other records mention levels at 80 ft and one map shows a sublevel originating along the Philadelphia No. 1 Shaft at 60 ft. The 100-level drift between the Philadelphia No. 1 and Philadelphia No. 2 shafts was reported as caved in 1931, and there are no reports that it was reopened.

Stoping was reportedly accomplished through shrinkage methods. In addition to the stopes shown on the Chock survey, a series of large stopes breaks open to the surface as tabular voids 5 to 15 ft across with random pillars (refer to Figure 6), dipping moderately, and widening beneath the surface. These surface stopes were probably the ones that removed the R-1, R-2, and R-A shafts, and were extracted after Chock did his survey. This indicates that at the Arabian, as with most abandoned metal mine projects, the available records typically portray the ***minimum*** extent of underground openings; undocumented workings exist.

Underground, the workings run chiefly along the strike. Crosscutting is indicated on old maps to have reached the footwall contact with the granite and the hanging wall contact with the gravel (Figure 7). This means that there is an efficient subsurface hydraulic connection between ground water and the workings. In fact, the workings are flooded below the 100 level and water has been extracted – in small quantities – in the past. Because of the flooding, none of the mine levels below the "100 level" could be accessed without extensive pumping of the mine. Water levels now are very similar to those reported in the records from as long ago as the 1930s.

Figure 7 – Crosscut ending in gravel off the Philadelphia No. 1 shaft

Other miscellaneous workings, including a shaft and an adit extending back into the granite footwall mass, and a vertical shaft, are found several thousand feet southwest of the main mine workings. The shafts are presently filled a short distance below the surface. The hilltop behind the workings contains numerous trenches, shallow prospect pits, and short adits, all of which are above the main shaft elevations (Figure 8, next page).

According to USBM Information Circular 6901 (1936) the mine was taken over by a new owner in 1933, in which year the mine produced 593 oz gold and 1,156 oz silver. In 1935, mining was actively proceeding.

Figure 8 – Panoramic view of Arabian Mine site with realigned curve at extreme left

Also, in 1934-1935, gold was recovered from a surface operation known as the Arabian Cut, on the Rising Fawn claim a little over 1,000 ft south of the underground workings, opposite the future curve realignment (Figure 9). According to the Arizona Department of Mineral resources in a report dated October 9, 1940, some development took place in the Philadelphia No. 1 shaft by new owners.

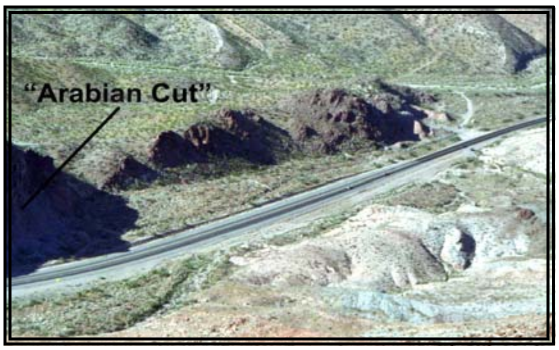

Figure 9 – Arabian Cut

Production essentially ceased in 1942 due to the Gold Order. Reportedly, new owners have intermittently recovered small quantities of ore since 1980. Various major mining companies have reviewed the property over the years but none has undertaken more than exploratory boreholes. In the 1990s, the mine owners commissioned studies of open pit potential in the former Arabian Cut area.

By the time the mine came under consideration for roadway widening, the Arabian Mine had not been worked for some time. Some open workings were evident at the surface (Figure 10). Some workings consisted of shallow holes connecting former stopes (Figure 11, note small diameter polyethylene pipe used to extract water).

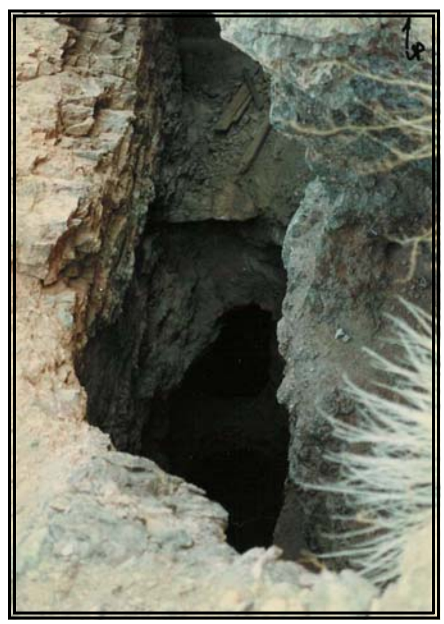

Figure 10 – Stopes open at surface

By the time ADOT commenced its studies, open stopes and shafts had stood for decades; some had remained open since the mine's period of active operation (compare Figures 12 and 13, next page), with remarkably few changes. Fencing of these very hazardous openings had deteriorated to where it was almost totally ineffective in denying casual public access, so ADOT installed chain link fencing and razor wire to mitigate the hazards.

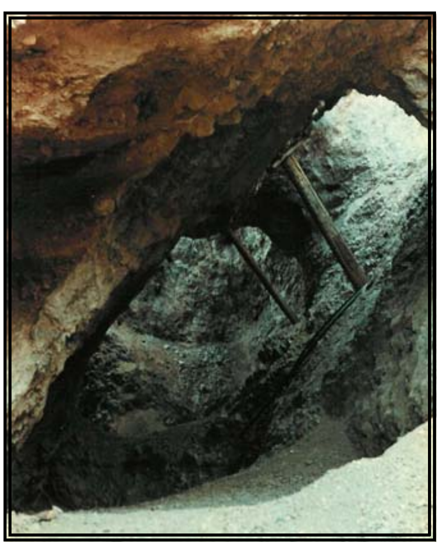

Figure 11 – Stopes used for water extraction

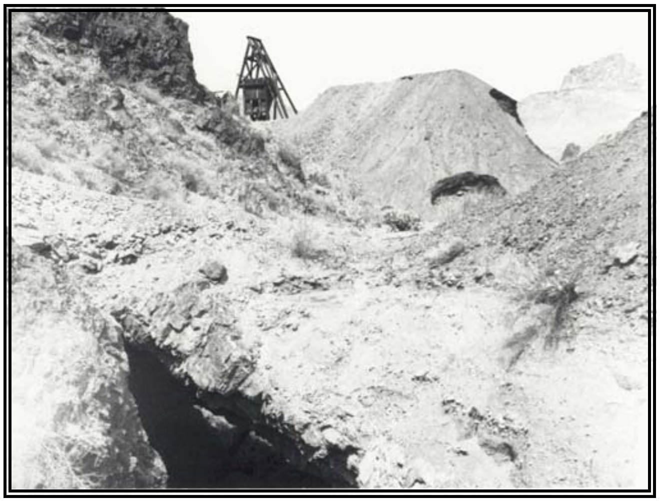

Figure 12 – 1930s view of stope and headframe

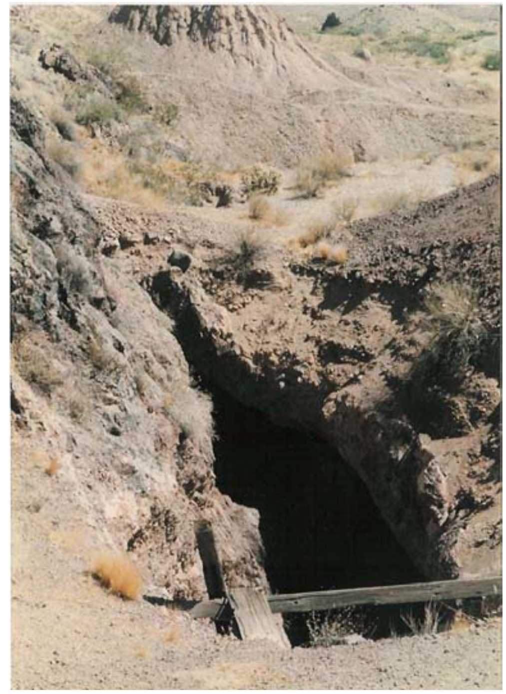

Figure 13 – 1990s view of area in Figure 12

<u>Mine Geology</u>

The mine was developed along a steeply-dipping rhyolite dike that intruded an older granitic mass, apparently along a significant fault zone. The shallower portions of the hanging wall of the dike contact gravel fill that comprises the adjacent wash (see Figures 14 and 7). Inasmuch as the wash drains a considerable portion of the surrounding upland terrain, the mine was wet during the period of operation, reportedly making about 35 gpm. Even today, most of the old workings are flooded; the mine pool can be seen from the surface in some open stopes. Lausen's (1931) description of the Arabian Mine geology was referenced for the study since most of the underground workings are inaccessible:

> *"At this time, a rhyolite-porphyry dike intrudes, and along the hanging wall of this dike, the rhyolite tuff has been faulted against the dike. The vein occurs in the dike, close to the fault and strikes northeastward while the dip is 82 degrees to the southeast. A mineralized zone, thirty feet wide and consisting of a number of quartz stringers, occurs in the rhyolite dike and, to a certain extent, in the granite footwall. The individual veinlets of this zone vary in width from a fraction of an inch up to twelve inches or more. The veinlets are chiefly quartz, but in some places, consists of coarse-grained gray calcite."*

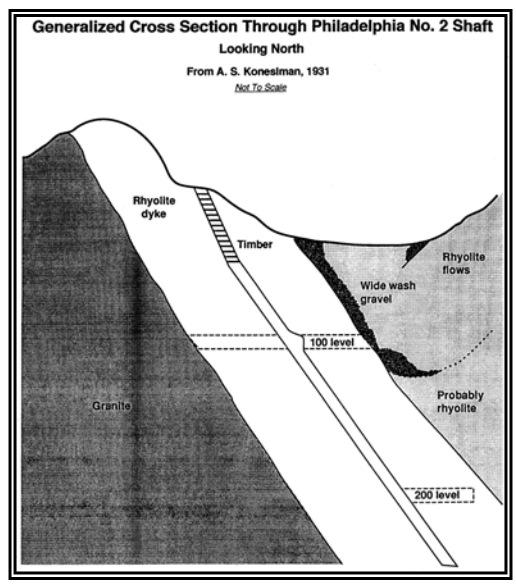

Figure 14 – Conceptual cross section through Arabian vein

The deeper portions of the dike hanging wall are in fault contact with porous rhyolite tuffs. The mineralized zone reportedly averaged about 30 ft wide, chiefly within the dike but also extending into the granite footwall, consisting of quartz stringers. Although Lausen notes that the Arabian vein dips 82 degrees overall, the inclinations of the main production shafts, the Philadelphia No. 1 and Philadelphia No. 2, do not match the steep inclination of the vein, but have a shallower slope in their accessible reaches.

APPROACH

The study of the mine and its potential impacts on the expansion of SR 68 began with a literature search. Shortly thereafter, in order to relate the physical position of the workings with the proposed alignment, and also to ascertain the present condition of the workings, a mine survey and reconnaissance was contracted. That work led to a program of geotechnical borings and cross hole geophysics to further resolve the underground conditions. Attempts were made to secure an appropriate borehole video camera capable of obtaining imagery of suitable quality in the water-filled stopes, no suitable equipment was located that met the budget and time constraints at the time.

LITERATURE REVIEW

As part of the corridor analysis it was necessary to review the original construction documents from the 1942 road building efforts. It was discovered that the roadway had been built over abandoned mine workings. Examination of the vicinity during a field review identified several areas that exhibited unsecured mine workings of significant depth.

Beginning in the early 1990s, a search was conducted at the local historical society to determine if any of the original engineering documents had survived and were now a part of the public record. The property owner was contacted to determine what materials were available for review. The U.S. Bureau of Land Management was researched to locate land and mineral survey maps and notes. Additionally many other state and federal agencies were contacted whom may have details about the mining activity at the project area and in the region. Technical journals, newspapers, and district reports were also investigated for published articles that related details about the production activity of the mine.

Fortunately some underground mine surveying records had been preserved as historic documents, for assessment of the general geometry of the mine workings and mining methods. Unfortunately, development on the property had continued beyond the survey date and there was a lot of speculation about what progress had been made before the mine was closed in the 1940s. Not unexpectedly, some records were found to conflict with others, and it became difficult to separate factual from anecdotal information. Reliable information came from the few photographs available from the mine's period of operation (for example, Figures 15 and 16) and some authoritative reports whose data were confirmed by other records. The most serious information gaps related to the actual depth of mining and widths of stopes at the close of active mining, plus conflicts as to the inclination of the Philadelphia No. 2 shaft, critical factors in ascertaining the degree of undermining of the highway. In addition, the records contained hazy references to a connection between the main workings and the workings on the Rising Fawn claim, including a reference to a 60-ft-deep shaft that may have underlain the roadway near the realigned curve.

Figure 15 -- Arabian Mill circa 1930

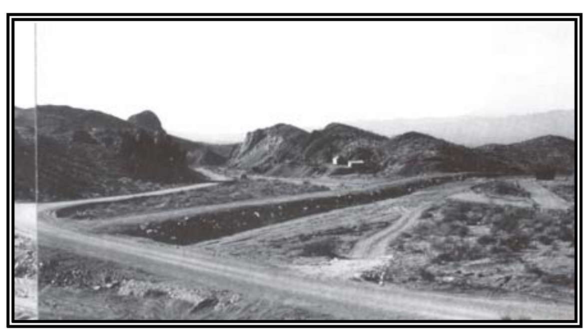

Figure 16 – Mine site and mill (unknown date)

Despite the shortcomings, the historic survey data offered an opportunity to at least qualitatively relate the location of underground mine workings to that of the highway corridor. A dependent resurvey of the original land lines with recorded ties to the main shafts was attempted. Most of the original survey monuments were no longer in existence, therefore, only an approximate location was possible. It was determined that further study of the mine maps in conjunction with underground reconnaissance should be made.

MINE SURVEY AND RECONNAISSANCE

In 1991, ADOT contracted with Engineers International, Inc., an engineering firm with an office in Tucson, that specialized in mine stability and mine subsidence, to document the occurrence and condition of accessible underground workings with respect to the proposed roadway improvements and right of way. Accessible portions of the underground workings were inspected, mapped and surveyed, to the extent that safe access permitted. From this information, additional confidence was gained in extrapolating the location of the inaccessible workings from the available records and surveys. The underground workings were inspected under a Site Safety Plan for confined space entry written by EI and approved by ADOT.

Figure 17 – Accessing the Philadelphia No. 1 shaft and removing hazardous ladders

Subsurface access was obtained using ship's ladders. At the Philadelphia No. 1 Shaft, the ship's ladder was hung over a pipe framework placed over the shaft collar (Figure 17). The Philadelphia No. 1 shaft collar timber was found to be in good condition. Hazardous old ladders and other debris were hoisted out of the shaft and discarded. The ladders were later destroyed to prevent unauthorized replacement of these hazards into the shaft. At the Philadelphia No. 2, there was no safe way to set the pipe framework without disturbing an old timber loading platform and the debris atop it, (Figure 18) so pins were set at the collar to affix the shaft ladder at the surface. Concern for damaging the shaft collar timber, and the very limited working room around the collar, prevented more than 35 ft of ship's ladder from being lowered into the Philadelphia No. 2. Further access had to be gained by climbing down the old steel rail in the shaft which would not accommodate the transport of gear needed for deeper ventures. This limited the investigation of the No. 2 shaft workings to those that were horizontal, continuous, and accessible by foot.

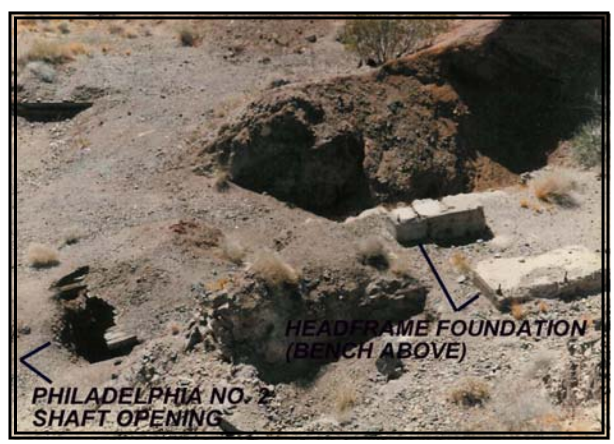

Figure 18 – Philadelphia No. 2 shaft in 1991

Because not all portions of the underground workings were accessible, it was not feasible to directly observe and measure the position, dimensions, and condition of the deeper workings, some of which were apparently developed subsequent to the available records. The underground survey pertained to those workings that were safely accessible without extraordinary effort.

The scope entailed an initial reconnaissance and site briefing, the underground survey with photographic documentation, and the preparation of mine level maps and cross sections showing the relation of the workings to surface features. Standard mine surveying methods were used. The general conditions of the accessible workings were observed and recorded with notes and photographs. The initial reconnaissance included an overall site inspection with notation of all surface features according to station and offset from roadway plans provided by ADOT. The principal surface workings were tied into the existing survey control.

Workings recorded in the survey, or indicated in the records, were depicted on maps, and cross-sections,

Figure 19 – 100 Level stope off the Philadelphia No. 2 shaft

relative to the location of the roadway corridor. The assessment of the integrity of the mine workings and the likelihood and character of potential threats to the roadway due to the presence of the workings underneath it (particularly the stopes), could not, because of the flooding, be observed directly. Underground observations did show that the stopes cannot be accurately described as regular, tabular voids that have consistent orientations (Figure 19).

Comparison of the old records with present conditions reveals that the Philadelphia No. 2 Shaft no longer collars at the same elevation it originally did. Shaft timbers once extended about 44 ft below the collar; they presently stop a little over 10 ft down, apparently from unrecorded mining of the dump material that once comprised the shaft walls. The remaining timber was found to be mostly loose and hanging, with free-running gravel behind, making mine entry hazardous. The inclination was measured at 48 -50 degrees, slightly steeper in the timbered portion.

The Philadelphia No. 1 Shaft is inclined downward at an angle of 57 degrees. It opens at the bottom into a chamber (Figure 20) that probably served as the shaft station and loading station. Rock conditions in the shaft itself are excellent. Branching drifts appear to be the same ones shown on a 1916 survey map, which corresponds quite closely to the results of the EI survey. None of the Philadelphia No. 1 workings appears to persist as far as the roadway. The furthest drift to the east is nearly filled to the back and stops at the contact with the gravel (see Figure 7). The entire level seems to be above the water level at all times, and there are no drips or seeps, although some locations of minor past seepage were noted. The gravel is very dense and compact, and tends to fall in chunks. It may be weakly cemented. The ribs in general are drummy and the rhyolite, though silicified and intensely fractured or crushed without much clay, is fairly soft. One fault contains as much as 1 ft of slickensided, clayey gouge, and has spalled moderately (Figure 21). The stability of the workings is probably attributable mostly to the absence of rock stress, owing to the shallow depth.

Figure 20 – Chamber at bottom of Philadelphia No. 1 shaft, with crosscut ahead

Figure 21 – Rib spalling in fault zone, 60- Level drift off the Philadelphia No. 1 shaft

From the No. 2 shaft, it was seen that the stopes are very extensive both down the dip and along the strike. It was possible to discern the continuation of the "100" level past the stope in both directions, although reaching them was impossible due to interfering workings and loose zones.

The accessible portions of the "100" level coincide closely with Chock's and other maps. However, it appears that an ore chute was added above the stope on the south side of the No. 2 shaft that is not shown on any maps, and this suggests that a shallower stope and some deeper workings may not be shown on Chock's map. To the north, the "100" level has been partially filled with muck. To the south, the level cannot be accessed from the shaft because to do so would require traversing a loose muck slope at the top of a deep, water filled stope. The drift appears to be open (Figure 22) but it doglegs to the left and conditions beyond remain unclear.

Figure 22 – 100 Level drift south from Philadelphia No. 2 shaft

Accessible stopes were generally open, despite prevalent raveling and drummy ribs. No large slabs or extensive cracking was noted. The striking feature of the stopes in terms of assessing their dimensions and stability is the irregularity in dimension perpendicular to the dip. Vertical distances to the stope backs range up to an estimated 40 ft and stope widths range between 10 ft and an estimated 40 ft. Apparently, stopes were widened along ore shoots that may have been elongate perpendicular to the general structural trend. There are no level maps that depict the dimensions of the stopes in this direction, although it appears that the Chock longitudinal section may be a good source of estimated stope lengths along the strike. One report (ca. 1915) describes a "hanging wall ore shoot" at the 200 level as being about 35 ft wide, which may be indicative of stoping widths. Stopes next to the shaft were observed to disappear into the water for as far as could be seen (Figure 23).

Figure 23 – Water-filled stope off the Philadelphia No. 2

Surface reconnaissance revealed numerous short adits, shallow prospect pits, and sampling trenches. None of the other workings could be proven to connect with the main Arabian Mine or the stopes that were part of the Philadelphia Group, despite historical accounts of more extensive underground workings. It was concluded that most of the shallow workings that are no longer visible were either mined through using surface methods (the "Arabian Cut", a benching operation along the surface expression of the vein nearly 150 ft high and 60 ft wide, that was mined in the 1930s), were proposed but never built, or were reclaimed in earlier phases of roadway construction. Vague references to a connection between the main mine workings and shallower workings to the south could not be confirmed.

Where underground observations were possible, stope as well as drift deterioration appeared to be a progressive occurrence characterized by raveling and sloughage, rather than large-scale block failures. Rock mass strength was observed to be low in much of the rock, and faults with gouge were seen to have considerable spalling and sloughage.

Little timber remains except in the shafts, and timber was probably minimally used in drifts due to its scarcity in the area. Stulls were used sparingly as stope support, if at all. The principal mode of stope support seems to have been pillars of natural rock, probably relatively barren vein material. All the pillars within the stopes observed are hourglassed to some degree; the smaller pillars more severely than the larger ones. This indicates that sloughage from the sides of pillars has been occurring. However, the length of time that the workings have remained open argues that the sloughage process is very slow overall, and should remain so unless major changes occur. Where the hanging wall is an extrusive, massive rhyolite, extensive spans could be maintained.

It was concluded that the proposed new road alignment, to the west of the existing, would be underlain by stopes and drifts whose orientations, dimensions, or stability could not be observed directly. It was recognized that even substantial ground failures in single drifts would not affect highway integrity. No such drifts would occur shallow enough beneath the alignment to cause subsidence because the miners consistently avoided crossing through the gravels, according to the few cross-sections available. It was noted that failures of single drifts have occurred on the 60 and 100 levels and there is no evidence of surface subsidence.

On the other hand, the potentials for failure of the stopes, and the effect any such failures might have on the ground surface, were of concern. The stopes accessed are open or water-filled; there is no indication that any were backfilled. Observed stopes are of sufficient size that their collapse could affect the surface significantly.

Several sources of potential underground collapse were identified that could lead to surface disturbance. Major changes in water level could introduce further sloughing of pillars or may cause pore pressure changes within the gravels, perhaps leading to collapse of certain areas. Excessive blasting vibration from future mining or road construction, placement of thick fill atop the mine workings, seismic events leading to slippage along faults, introduction of fluids (mine leachate or other) into the mine, and other mechanisms leading to stress regime change, were identified.

The surface expression of underground stope failure could not be pinpointed in this case; it may range from zero to considerable. The considerable vertical extent of the workings, the presence of faults and other discontinuities that dip moderately to steeply, the presence of weakly-consolidated gravels, and the relatively shallow depths of the larger stopes beneath the road, indicate that stope collapse would be very likely to affect the surface. Surface movements of feet to tens of feet could very well occur as a result of massive stope collapse, particularly if the collapse occurred at shallower depth so that collapsed material could move downward through water-filled workings. It was recognized that proper construction blasting at the distances under consideration would not be likely to trigger the scale of stope collapse that would be prerequisite to large-scale ground movement, unless that collapse is imminent anyway.

Based on the recommendations from the subsurface reconnaissance, ADOT arranged for a subsurface drilling and geophysical program. It also fenced the hazardous workings, took steps to limit the extent of water withdrawal from the workings, and instituted criteria to limit construction blasting vibrations in the area.

INVESTIGATIVE BORINGS AND CROSS HOLE GEOTOMOGRAPHY

In 1992 the Arizona Department of Transportation (ADOT) and the U.S. Bureau of Mines (USBM) jointly entered into a Cooperative Research and Development Agreement (CRADA), to test, at the Arabian mine, a prototype cross well tomographic system's ability to identify shallow voids at abandoned mines. The USBM prototype system consisted of a high frequency ceramic-piezoelectric, cylinder-bender, transducer source, and a wall locking, triaxial acoustic receiver. (The following description is abstracted from Killoran, 1992.)

Acoustic Tomography

Cross well acoustic tomography methods were developed by the oil and gas mineral exploration industries to produce a better image, based on velocity, of the geologic structure between two boreholes. In cross well tomography, a transmitter probe is placed in a borehole and electrically excited to produce an acoustic wave. This wave propagates through the rock mass to a receiver probe in another borehole. The receiver signal is recorded and evaluated for the first arrival travel time.

Since the velocity of an acoustic wave is dependent on the media through which it travels, this velocity time represents the fastest path, that the wave can travel through the intervening rock mass. This implies that the acoustic wave travels the shortest time path through the media. If a void, filled with air or water is present between the transmitter and the receiver, the first arrival travel time will be greater than if no void is present because the first arrival path will travel around the mine opening. By placing the transmitter and the receiver at numerous depths in the boreholes, a cross section of travel times can be recorded.

Tomography programs are then used to construct an image of the two-dimensional cross section between the boreholes using the first arrival travel times, the transmitted and receiver probe depths, distance between boreholes, and an initial estimate of the velocity field. The cross section is divided into rectangular "pixels" with a velocity associated with each pixel. The tomography program traces a ray path through the pixels from the transmitter to the receiver and computes the travel time. After all the ray paths have been computed, the velocity values are adjusted to minimize the differences between the measured travel times and the computed travel times. Geological and man-made subsurface features between the boreholes can then be interpreted from the final velocity distribution shown on the tomogram.

Supplemental Borings

To facilitate the cross well geophysical tests ADOT provided seven vertical reverse circulation boreholes at the Arabian mine site (Figure 3). The borings were drilled in two phases. Phase 1 borings were drilled to obtain information concerning the extent of the main workings (1, 2, 5, and 6). Phase 2 was drilled in an attempt to determine the extent of the underground workings to the southwest (B1 through B3).

The first phase borings were cased with plugged schedule 40 PVC pipe. However, the PVC would not maintain a constant head of water above the ground water table. The second phase borings were cased with plugged schedule 40 steel pipe and did maintain water to top of the casing. However, the steel casing attenuated the high frequency signal and inhibited a clear reception at the receiver.

The Phase 1 borings and tomographic profiles were partially successful in identifying underground workings below the ground water table. Mine voids were intercepted in Borings 2 and 5, probably corresponding to stopes extending between the 100 and 200 levels. In Boring 2, a 16 ft high void was first intercepted at a depth of 103 ft (undoubtedly a stope) and another void 4 ft high was intercepted 16 ft below the bottom of the first, corresponding either to a stope irregularity or a drift. In Boring 5, an 11 ft high void, probably another stope, was encountered at a depth of 218 ft.

Interpretation

One successful tomographic profile is indicated in Figure 24. The darker red zones are low-velocity areas interpreted as open or water filled voids.

There was some confusion when considering the depths at which these voids were encountered, which seem to be too shallow for the levels designated. However it must be remembered that the records indicate that levels were designated relative to the original collar down the main production shaft, and that it was determined that around 30 ft (slope distance) of the Philadelphia No. 2 shaft collar is missing, so all levels would occur around 25 ft shallower on that account.

When the tomogram shown in Figure 24 is plotted against the most plausible interpretation of the extent of stopes between the 100 and 200 levels, together with the geologic interpretation drawn from available boring logs and geologic cross sections, a close agreement is obtained.

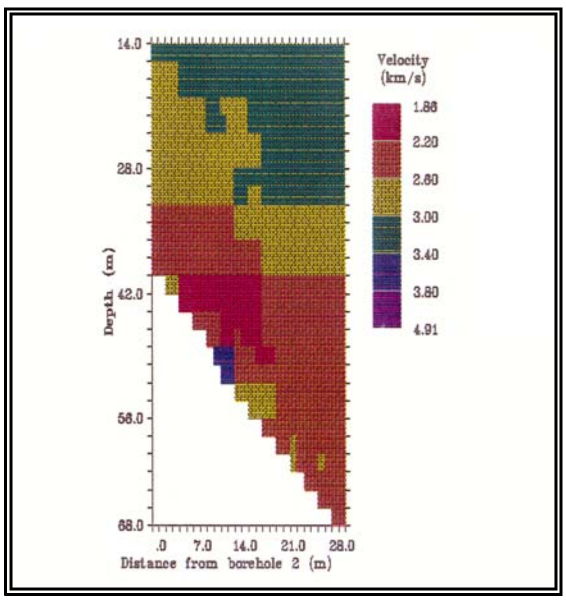

Figure 24 – Tomographic profile between boreholes 2 and 5

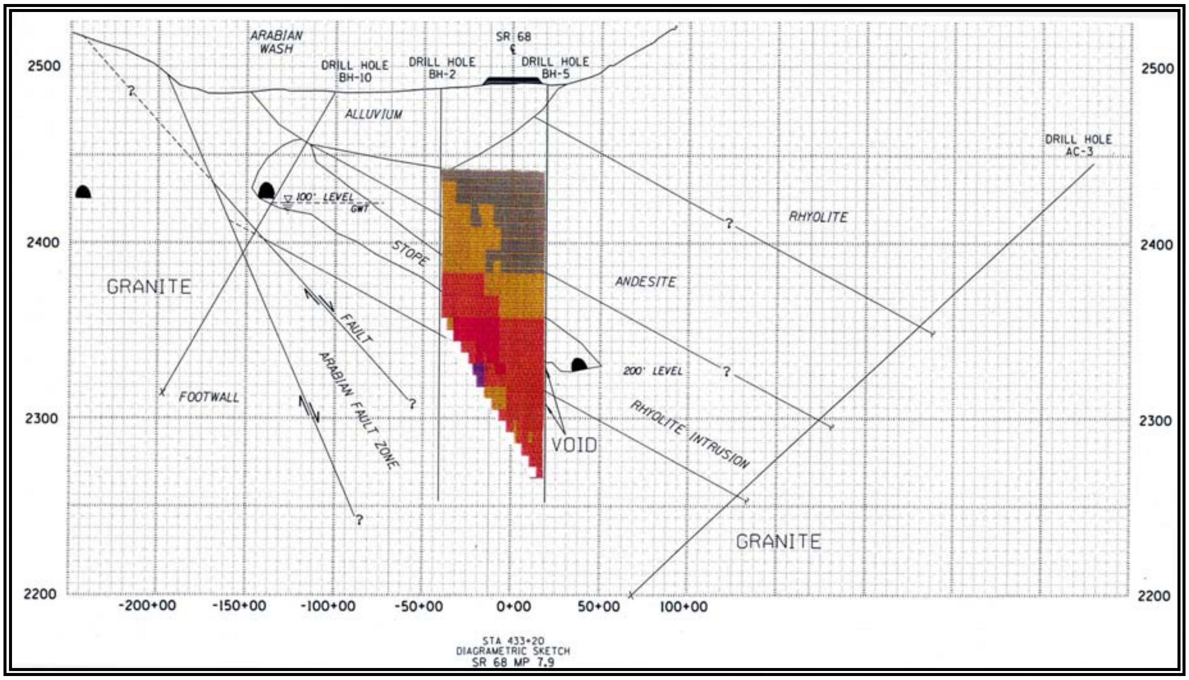

Figure 25 – Geologic interpretation of tomography between borings 2 and 5

Figure 25 shows regions corresponding to the gravel fill in the wash bottom, and to the occurrence of voids representing a large stope. Moreover, the tomogram shows that the hanging wall rock may be only a few meters thick, as indicated by the separation between the top of the low velocity (red) zone and the zone (green) representing low-velocity earth materials (possibly weak gravel or altered/weathered andesite). This condition is shown on the cross section to directly underlie existing SR 68. The expansion would have provided a new westbound set of lanes which would appear to the left of the roadway prism diagramed in the cross section. That location would clearly have been underlain by even shallower mine workings with thinner hanging wall rock overlain by gravel. Note that the groundwater table was observed to be just below the 100 level.

The Phase 2 borings and associated tomographic profiles did not produce reliable data and no conclusive interpretation was given by the USBM. However, altogether the acoustic tomographic images of the flooded underground workings suggested that they were much more extensive than what was anticipated from the surviving mine records.

CONCLUSIONS

Just as permanent civil structures are designed and constructed for higher reliability than transient industrial facilities (like mines), the standard of "geotechnical stability" is higher where public highways are concerned. It is within this framework that the potential impact of the Arabian Mine had to be evaluated. Assuring the convenience and safety of the traveling public was, and remains, the paramount concern for ADOT.

The Arabian Mine, like most deep metal mines, is both geologically and geometrically complex. Unfortunately, despite years of records review and field work, practical constraints prevented developing the subsurface geotechnical data needed for a thorough evaluation of mine opening stability. The range of potential spans and depths was too great and too uncertain, and geotechnical parameters could not be reliably derived for the pillars and surrounding rock, not to mention the faults. Furthermore, inconsistencies in the available records limited the reliability of the information developed. To resolve this, a lengthy and expensive subsurface investigation would have been required.

Nonetheless, the data clearly showed that not only is the existing highway undermined, but the new, realigned highway would be undermined as well, and at a shallower depth where a greater percentage (perhaps more than 75%) of the overburden thickness is represented by weakly cemented gravel. In addition, direct observations disclosed spalling, pillar hourglassing, locally weak, heavily fractured to shattered and clayey rock conditions, and a groundwater table that, while fairly stable in the past, could produce pore pressure changes in the mine support structure should it fluctuate in the future. Although there is no proven history of subsidence other than that induced on purpose as the result of overhead stoping, this does not assure demonstrate future stability for the development of a public transportation corridor.

Distress to the support system in a mine as the result of ground water level fluctuation (not necessarily complete drying, which can have even more severe effects) results from a pressure imbalance within the supporting rock, because the openings depressurize more rapidly than the surrounding rock can drain. Instances of subsidence induced by surface or ground water disturbance are not unheard of, although they are not commonly reported. Several instances, published and unpublished, of the collapse of mine structures due to ground water withdrawal or drastic ground water level changes are known to the authors. This possibility added to concern for building a new highway over the mine.

There are engineering solutions to the potential for subsidence. Mine backfilling was considered but dismissed due to the cost, time required, and the fact that it would sterilize the mineral estate, necessitating what was assuredly going to be the difficult task of negotiating the property's value with the mine owner(s). Likewise, applying an engineering solution at the surface ("subsidence-proofing") the highway was known to be complicated due to the high subsidence factors that would have to be considered, and the remoteness of the site.

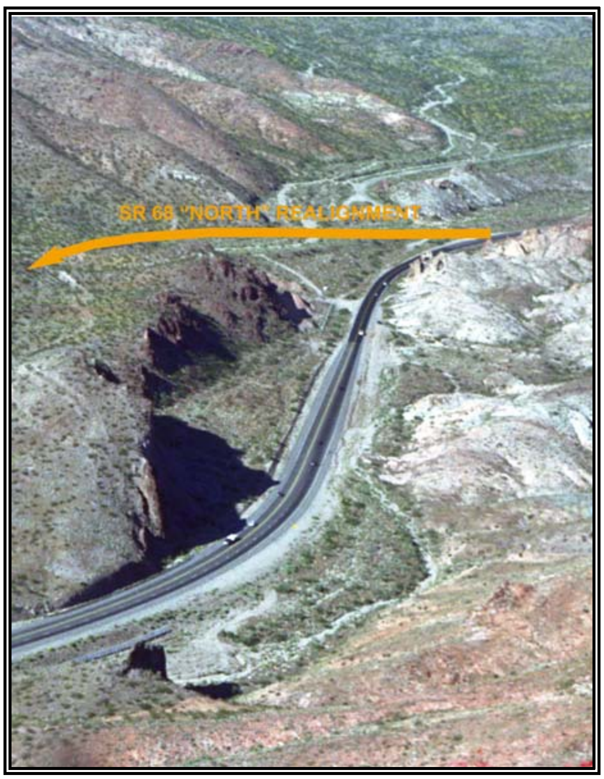

Figure 26 – "North" realignment

At other, more constrained sites, perhaps such engineering solutions could not be avoided. In this case the argument for relocation was compelling, even though it is often most convenient to expand the existing corridor rather than relocate it. In the end, the decision was taken to realign the highway to the north (Figure 26), through public land (and a few unpatented claims) that was known to be free of undermining. As it turned out, in part because the new construction could take place without interference from existing traffic, and in part because ROW acquisition did not have to be negotiated with the current Arabian Mine owner(s), the eventual cost of construction proved to be less than the projected cost of the improvements within the existing corridor.

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